HILGARDIA

A JOURNAL OF AGRICULTURAL SCIENCE PUBLISHED BY
THE CALIFORNIA AGRICULTURAL EXPERIMENT STATION

Volume 52 • Number 7 • June 1984

Sampling Mites in Almonds:

I. Within-Tree Distribution and Clumping Pattern of Mites with Comments on Predator-Prey Interactions

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II. Presence-Absence Sequential Sampling for *Tetranychus* Mite Species

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I. Within-Tree Distribution and Clumping Pattern of Mites with Comments on Predator-Prey Interactions

Tetranychus spp. and peach silver mite, *Aculus cornutus,* are distributed randomly within the foliage of almond trees. Both, however, have extremely clumped patterns of distribution on a per leaf sample unit. The pattern of distribution for *Tetranychus* spp. was additionally affected by the phytoseiid mite, *Metaseiulus occidentalis,* the pattern being less clumped with the predator present. *M. occidentalis* was considerably less clumped than observed for the other mites. Additional analyses indicate that, except at low *Tetranychus* spp. densities, approximately one *M. occidentalis* per ten *Tetranychus* is sufficient to reduce the prey density 2 weeks hence. The distribution relationships in this paper provide a framework for development of a quantitative *Tetranychus* spp. monitoring program, presented in the following paper.

II. Presence-Absence Sequential Sampling for *Tetranychus* Mite Species

A practical monitoring program for spider mites, *Tetranychus* spp., in almond orchards is proposed. It is possible to determine densities of the *Tetranychus* mites after they disperse through each tree by using the proportion of leaves infested with one or more mites rather than counting the actual number of mites per leaf. This presence-absence (binomial) sampling technique may be used in conjunction with sequential sampling to further reduce sampling time. Provisional control action thresholds developed are 0.436 (mean proportion infested leaves) in the presence of the predatory mite *Metaseiulus occidentalis,* and 0.220 in its absence. Optimal numbers of trees to be sampled at various confidence levels are determined for a range of mite densities with leaf samples of 5, 15, and 40 per tree.

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II. Presence-Absence Sequential Sampling for *Tetranychus* Mite Species[1]

INTRODUCTION

BARNES AND CURTIS (1979) associated six species of tetranychid mites with almond trees in California's Central Valley. These include the European red mite, *Panonychus ulmi* (Koch), the citrus red mite, *P. citri* (McGregor), the brown almond mite, *Bryobia rubrioculus* (Scheuten), and three species of web-spinning mites, the two-spotted mite, *Tetranychus urticae* Koch, the Pacific spider mite, *T. pacificus* McGregor, and the strawberry spider mite, *T. turkestani* Ugarov and Nikolski. *P. ulmi* and *B. rubrioculus* are most often associated with the northern and central portions of the Central Valley (Hoy et al. 1978). *P. citri* is most often associated with areas of citrus production in the southeastern portion of the Central Valley. These three species occasionally occur in sufficient abundance to necessitate chemical intervention by growers. The three *Tetranychus* species reach high populations annually in many areas, and foliar treatment for their control is utilized on a substantial portion of the almond acreage. Most treatments are made at the onset of infestations which usually occur in late June or early July (Barnes and Curtis 1979). More severe infestations are reported in the southern part of the valley than in the north (Summers 1962).

In their review of the ecology of tetranychid mites, van de Vrie et al. (1972) concluded that little is known about the maximum levels of mites that can be tolerated without economic loss in most crops. Mite feeding reduces chlorophyll content of leaves (Chapman et al. 1952) and may interfere with leaf vascular tissue (Avery and Briggs 1968). Premature leaf abscission may result from intensive mite feeding. Partial defoliation of almond trees results from mite infestations that remain uncontrolled (Barnes and Curtis 1979). Barnes and Andrews (1978) have shown that crop size and nut quality were not affected in the first year of such infestations. However, in the second year crop size was reduced, and both terminal and trunk girth growth were decreased. Westigard et al. (1966) demonstrated similar effects of feeding by *T. urticae* on mature Anjou pear trees in Oregon during a 3-year period. Some leaf recovery following mite feeding has been reported by Chapman et al. (1952) in apple. This is apparently associated with less intense although prolonged injury.

Tetranychus mite injury is related to many variables, with their influences difficult to estimate (van de Vrie et al. 1972). This is especially true of perennial crops such as almonds where economic damage is not manifested until the year following injury. Quantifying the sustained physiological effects of mite feeding in such situations is difficult because of problems in controlling environmental influences acting on the orchard over an extended period of time (Brito 1980). At present, no control action thresholds based on the physiological effects of mite feeding have been developed for almond.

Huffaker et al. (1970) reviewed several general factors that influence the abundance of tetranychid mites including features of their life cycles, meteorological conditions, host-plant

[1]Submitted for publication October 7, 1983.

nutrition, actions of natural enemies, and horticultural programs including the use of chemicals. They cited the development of better sampling techniques as one of the difficulties inherent in the study of ecology and natural control of tetranychids. Some examples of methods include:

1. Counting all mites directly on the leaves.
2. Counting only adult females (Jeppson 1951).
3. Washing mites from leaves and subsampling the solution while agitating (Jones and Prendergast 1937, Newell 1947, Henderson 1960, Leigh et al. 1984).
4. Counting mites only on portions of the leaves (Hoskins et al. 1938, Baten and Hutson 1943, Michelbacher 1959).
5. Leaf-imprint method (Venables and Dennys 1941).
6. Mite-brushing machine (Henderson and McBurnie 1943).
7. Counting mite-free leaves only (Pielou 1960).
8. Knocking mites from foliage (Summers and Baker 1952, Boudreaux 1953).
9. Recording proportion of infested leaves from specific strata of a plant (Wilson et al. 1983a).

Sampling is also a problem in the decision-making process of growers and their fieldmen who must obtain a reliable estimate of control status or population density while maintaining efficiency of monitoring time. Counting small and often abundant organisms such as *Tetranychus* mites can be time consuming. Further, some conventional techniques may provide an inaccurate population estimate due to the loss of individuals by disturbance. The principal objective of this study was to develop a practical sampling scheme for *Tetranychus* mites in almond orchards.

Presence-absence (binomial) sampling techniques offer an alternative to enumerative sampling where each individual is counted. In presence-absence sampling, each sample unit is examined for the presence of one or more individuals of a particular species, not the number present. Based on an intrinsic relationship between the proportion of infested sample units and the density of individuals of a species on the sampled unit, the control status or density of the species can be assessed. Wilson and Room (1983) developed such relationships for 20 plant parts and arthropods in Australian cotton. Wilson et al. (1981), using the procedure for spider mites on cotton, took 1 minute per leaf or less (depending on density) compared with up to 2 hours per leaf using a microscope to estimate population density. Further reductions in sampling time can be achieved through sequential sampling (Wald 1945), particularly when used in conjunction with binomial sampling (Ingram and Green 1972, Sterling 1975).

Methods

Information required to develop a quantitative presence-absence sampling plan includes distribution of mites on a host, proportion infested/mean density relationships for mites on leaves, a provisional control action threshold, and a measure of acceptable risk and sampling cost provided by the user.

During the summer of 1982, three orchards were monitored weekly until an acaricide was applied. The orchards were situated near Livingston, Merced County; Three Rocks, Fresno County; and Madera, Madera County.

Five trees were tagged in the Livingston and Madera orchards for subsequent sampling. Ten trees were tagged in the Three Rocks orchard. The sample trees were chosen at random to insure coverage of the orchard, restricted only by the exception that no young or obviously weak tree was included. Each week, individual trees were observed for general appearance, webbing from mite activity, abundance of *Tetranychus* mites, and predatory insect and mite distribution. A judgment was made as to whether 1) no treatment was necessary (the potential for leaf abscission due to mite feeding was low), 2) a treatment was needed immediately (the potential for leaf abscission due to mite feeding was high), or 3) no decision could be made using imminence of defoliation as the decision criterion. Following these observations, 50 leaves were sampled at random from the perimeter of each tree above the sprinkler line. The presence or absence of all stages of *Tetranychus* mites and the predatory mite *Metaseiulus occidentalis* (Nesbitt) was recorded. Lumped distributions of all life stages were used as they have been demonstrated to minimize detailed field or laboratory operations, an important component of a practical sampling procedure (Croft et al. 1976).

The equations for developing presence-absence sequential sampling plans as used in this paper were first presented by Wilson et al. (1983b).

$$n_l = \tau_\alpha^2 \cdot (p - T_i)^{-2} \cdot p \cdot q \tag{1}$$

$$n_U = \tau_\beta^2 \cdot (p - T_i)^{-2} \cdot p \cdot q \tag{2}$$

n_l = sample size required to estimate with a given error rate (α) that the proportion of infested leaves level (p) is below the control action threshold (T) at any point in time (i) (lower control decision line).

n_U = sample size required to estimate with a given error rate (β) that the proportion of infested leaves is above the threshold (upper control decision line).

τ = the standard normal variate.

This method differs from conventional sequential sampling in that it requires only one threshold as opposed to using two thresholds where one of the thresholds is arbitrarily chosen as a percentage of the real threshold. The use of one threshold is more realistic than two in a pest management decision-making process.

Sequential sampling involves the use of α and β error rates where α is the probability of treating when the control action threshold has not been exceeded, and β is the probability of not treating when the control action threshold has been exceeded. Error rates should be assigned by considering the mite density-yield relationship, crop value, acaricide and application costs, and effects of treatments on mite resurgence and secondary pests. Information on density-yield relationships and treatment effects are unknown for almonds, as is true with respect to most crop-pest situations. We have arbitrarily chosen error rates of $\alpha = 0.10$ and $\beta = 0.05$, assigning greater importance to reducing the probability of not treating when treatment is warranted (β) than treating when no treatment is warranted (α). The population level (p) used in developing a presence-absence sequential sampling plan is the proportion of sample units having individuals present. In this case, it is the proportion of almond leaves sampled that are infested with *Tetranychus* mites.

The basic sampling unit of the presence-absence sequential sampling plan for *Tetranychus* mites on almonds is the leaf, as the original data were taken on the basis of mean number of mites per leaf for each tree sampled. It then becomes necessary to determine the number of leaves to sample from each tree to estimate overall mite densities within an orchard.

Karandinos (1976) proposed the following general formula to determine optimum sample size; we used the formula to determine optimum number of trees to sample.

$$n = (Z_{\alpha/2}/D)^2 \cdot (S^2/\bar{x}^2)$$

where $Z_{\alpha/2}$ is the upper $\alpha/2$ point of the standard Normal distribution, α the confidence level, D a fixed proportion of the mean, and $S^2/\bar{x}^2$ the variance/mean-squared relationship of proportion infested leaf samples between trees in an orchard. Between-tree variance for a range of mite densities with 5, 15, and 40 leaf samples were compared.

Results and Discussion

Figure II.1 indicates that there is a relationship between the proportion of leaves infested with *Tetranychus* mites and control decisions that were made based on observations of general tree appearance before spraying, and the presence of webbing, web-spinning mites, and *M. occidentalis.* Such observations are used by better growers and fieldmen as an indication of defoliation potential. The "no treat" decision meant that the potential for leaf abscission due to mite feeding was assumed to be low. The "treat" decision was made when the potential for leaf abscission appeared to be high. Occasionally, the observer was unable to make a decision based upon our monitoring criteria.

The mean proportion of leaves infested with web-spinning mites for the three categories of decisions (fig. II.1) were significantly different ($P < 0.01$) from one another. Further, only one data point for the "treat" decision was below the mean proportion of infested leaves for the "indecision" criteria ($\bar{p} = 0.436$).

In the absence of a suitable control action threshold for web-spinning mite injury to almond, we will utilize 0.436 (mean proportion infested leaves) as a provisional threshold when the predatory mite *M. occidentalis* is present in an orchard to develop sampling decision rules. By doing so, we assume that premature leaf abscission at any time of the season caused by the feeding of web-spinning mites will result in significant crop loss and loss of

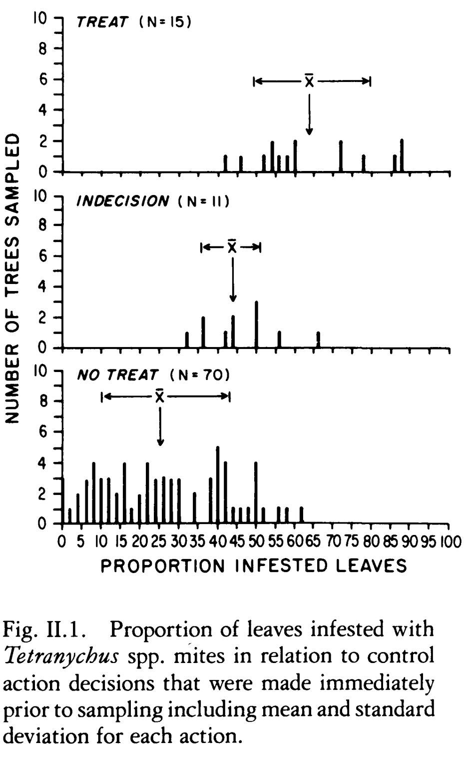

Fig. II.1. Proportion of leaves infested with *Tetranychus* spp. mites in relation to control action decisions that were made immediately prior to sampling including mean and standard deviation for each action.

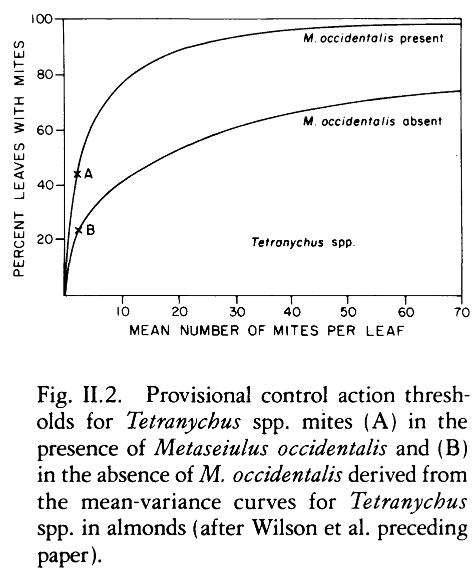

Fig. II.2. Provisional control action thresholds for *Tetranychus* spp. mites (A) in the presence of *Metaseiulus occidentalis* and (B) in the absence of *M. occidentalis* derived from the mean-variance curves for *Tetranychus* spp. in almonds (after Wilson et al. preceding paper).

tree growth in subsequent seasons if the proportion of infested leaves exceeds this value. We also assume that the almond tree host will tolerate moderate population densities without injury as has been shown by Westigard et al. (1966) on pear. Additional research on crop-stage specific thresholds may be necessary.

Using the proportion infested/mean density curves for *Tetranychus* mite abundance on almond derived by Wilson et al. in the first paper (figure II.2), it is possible to see that the provisional (control) action threshold 0.436 (A) proportion infested leaves in the presence of *M. occidentalis* is equivalent to 0.220 (B) proportion infested leaves in the absence of *M. occidentalis.*

Sequential sampling

Westigard and Calvin (1971) believe that integrated management of spider mites is feasible if trained personnel are available to evaluate changes in phytophagous and predaceous mite populations and are able to recommend appropriate control measures when needed. The alternatives to a monitoring program are "preventive" acaricide applications which may lead to resistance, resurgence, and secondary pest outbreaks, and "no intervention," which can lead to defoliation and subsequent crop loss. The major problems of sampling for *Tetranychus* mites in almonds are the time involved in counting individual mites and the reliability of those estimates. Sequential sampling can lead to a savings of as much as 65 percent compared with conventional enumerative fixed-sample size procedures having comparable error rates (Pieters and Sterling 1975). Presence-absence sampling can provide additional savings because instead of counting number of mites per leaf, only the proportion of leaves with one or more mites is recorded (Wilson et al. 1981).

Figure II.3 presents our estimate of decision rules for *Tetranychus* mites on almond when predators are present. As in conventional sequential sampling, the sample size depends on density. The proportion infested/mean density coefficients for *Tetranychus* mites established in the companion paper by Wilson et al. were $a = 6.005$ and $b = 1.566$ in the presence of *M. occidentalis* and $a = 20.156$ and $b = 1.628$ in the absence of *M. occidentalis.* The control action thresholds (T_i) used to generate our sampling decision lines were 0.436 proportion

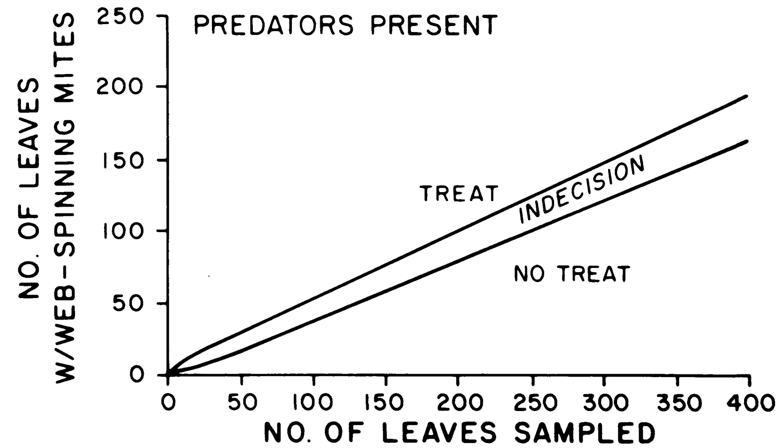

Fig. II.3. Presence-absence sequential sampling decision rules for *Tetranychus* spp. mites on almond in the presence of *Metaseiulus occidentalis.*

infested leaves in the presence of *M. occidentalis.* The decision rules for *Tetranychus* mites in the absence of *M. occidentalis* would be similar to those in Figure II.3 except that their slope would be lower reflecting the lower proportion infested threshold (0.220).

Table II.1 gives optimal numbers of trees to be sampled to estimate the abundance of *Tetranychus* mites at various mite densities expressed in proportion infested leaves (P(I)) given an acceptable percent error (D) in relation to the mean P(I), and an acceptable certainty of meeting the specified error level. The actual number of trees and individual samples, like the number of leaves per tree the individual chooses, will depend upon an estimate of acceptable sampling time and knowledge of the minimum treatment unit within the orchard. The latter is a function of the ability of the grower to treat a portion of the orchard as opposed to the entire orchard, and would require sampling subunits of the orchard independent of one another. To reduce the impact of between-tree variance in larger subunits

TABLE II.1. OPTIMUM NUMBER OF TREES REQUIRED TO ESTIMATE ABUNDANCE OF *TETRANYCHUS* SPP. IN AN ALMOND ORCHARD GIVEN VARIOUS MITE DENSITIES (P(I))

	Percent Error in Relation to Mean (D)														
	0.10			0.20			0.30			0.40			0.50		
	Leaves collected/tree														
P(I)	5	15	40	5	15	40	5	15	40	5	15	40	5	15	40
	95% certainty*														
.10	499	419	146	125	105	37	55	47	13	31	26	9	20	17	6
.20	319	131	88	80	33	22	35	15	10	20	8	6	13	5	4
.30	204	65	58	51	16	14	23	7	6	13	4	4	8	3	2
.40	127	42	35	32	11	9	14	5	4	8	3	2	5	2	1
.50	81	27	15	20	7	4	9	3	2	5	2	1	3	1	1
.60	50	23	8	12	6	2	6	3	1	3	1	—	2	1	—
.70	35	15	4	9	4	1	4	2	—	2	1	—	1	1	—
.80	19	12	—	5	3	—	2	1	—	1	1	—	1	—	—
.90	12	12	—	3	3	—	1	1	—	1	1	—	—	—	—
	90% certainty*														
.10	354	296	103	88	74	26	39	33	12	22	19	6	14	12	4
.20	226	93	63	56	23	16	25	10	7	14	6	4	9	4	3
.30	144	46	41	36	12	10	16	5	5	9	3	3	6	2	2
.40	90	30	25	22	7	6	10	3	3	6	2	2	4	1	1
.50	57	19	11	14	5	3	6	2	1	4	1	1	2	1	—
.60	35	16	5	9	4	1	4	2	1	2	1	—	1	1	—
.70	25	11	3	6	3	1	3	1	—	2	1	—	1	—	—
.80	14	8	—	3	2	—	2	1	—	1	1	—	1	—	—
.90	8	8	—	2	2	—	1	1	—	1	1	—	0	—	—
	80% certainty*														
.10	213	179	62	53	45	16	24	20	7	13	11	4	9	7	2
.20	136	56	38	34	14	9	15	6	4	9	3	2	5	2	2
.30	87	28	25	22	7	6	10	3	3	5	2	2	3	1	1
.40	54	18	15	14	5	4	6	2	2	3	1	1	2	1	1
.50	34	11	7	9	3	2	4	1	1	2	1	—	1	—	—
.60	21	10	3	5	2	1	2	1	—	1	1	—	1	—	—
.70	15	7	2	4	2	—	2	1	—	1	—	—	1	—	—
.80	8	5	—	2	1	—	1	1	—	1	—	—	—	—	—
.90	5	5	—	1	1	—	1	1	—	—	—	—	—	—	—

*Certainty of meeting the specified error level.

or orchards, the number of leaves sampled from each tree should be reduced, thus increasing the number of trees sampled (Croft et al. 1976).

Once a decision has been reached on the number of leaves to sample per tree and the minimum number of trees that will be sampled, a sampling form can be generated based on the type of control decision lines shown in Figure II.3. An example of a form where the sampling unit is 15 leaves per tree (table II.2) is provided. In this example, the probability of treating the orchard when not necessary (α) and not treating when necessary (β) would be 10 percent and 5 percent respectively. In general, error rates lower than those we suggest result in unprofitably high numbers of samples necessary for reaching a management decision.

Population growth potential

High temperatures induce rapid reproduction and development of web-spinning mites, and the greatest densities usually occur in midsummer (van de Vrie et al. 1972). Growers and pest managers are concerned by the presence of mites during times of high temperatures and low humidities because of the potential for severe injury and defoliation. An important component of a monitoring program is sampling frequency during critical periods of plant or pest development. One method of determining frequency is to monitor development utilizing physiological time.

TABLE II.2. SAMPLING FORM INCORPORATING PRESENCE-ABSENCE SEQUENTIAL SAMPLING RULES AND 15 LEAVES-PER-TREE SAMPLE SIZE

Almond Web-spinning Mite Sampling Form

Date ____________________ **Orchard** ____________________

Tree number	No. leaves sampled	Predators present No. leaves w/ web-spinning mites in each sample	Total no. leaves w/ web-spinning mites for all samples	Don't treat if <	Treat if >
1	15	______	______	4	10
2	30	______	______	9	18
3	45	______	______	15	26
4	60	______	______	21	33
5	75	______	______	27	40
6	90	______	______	33	48
7	105	______	______	39	55
8	120	______	______	45	62
9	135	______	______	51	69
10	150	______	______	57	76
11	165	______	______	63	83
12	180	______	______	70	90
13	195	______	______	76	97
14	210	______	______	82	104
15	225	______	______	88	111
16	240	______	______	94	118
17	255	______	______	101	125
18	270	______	______	107	132
19	285	______	______	113	139
20	300	______	______	119	146
	••• Stop Sampling •••				

Mori (1961) reported the lower limits of female *T. urticae* activity as 6.7° C to 13.0° C, and the upper thermal point at 45.0° C to 46.5° C. He also found the range of temperature preference for the species to be 13° C to 35° C. Utilizing *T. urticae* development rates at different temperatures published by Cagle (1949), Hussey et al. (1957), and Harrison and Smith (1961), we conclude that the lower developmental threshold for *T. urticae* is ca. 12° C.

The data used to generate provisional control action thresholds were analyzed to determine the increase in the proportion of infested leaves on each tree sampled between sampling dates. Physiological time for the web-spinning mites (° D > 12° C) was calculated for each interval utilizing local weather data (see Zalom and Wilson 1982 for procedure). Sampling dates where the proportion infested leaves declined due to unknown mortality factors or acaricide applications were excluded.

Our results (fig. II.4) show a significant ($P<0.05$) linear relationship ($Y = 0.198x - 1.669$; $r = 0.8602$; $n = 96$) between the increase in proportion infested leaves and accumulated heat (°D > 12° C) between sampling dates for web-spinning mites in the almond orchards studied. This is important as it indicates that during hot portions of the summer when an average of 13 degree-days may accumulate in a day the proportion of infested almond leaves can increase by as much as 0.18 in a week. Utilizing current sampling information to determine the status of mites in the orchard a sampler can determine the next sampling interval, but should sample each orchard at least once each week. This growth rate will probably be affected by the action of natural enemies, meteorological factors, or horticultural programs.

Monitoring *Tetranychid* mites in almonds

Foote (1965) studied the geotactic behavior of *T. urticae* on peach seedlings in Quebec and found that most of the diapausing females were positively geotactic while the non-diapausing females were negatively geotactic. This behavior helps to explain the seasonal

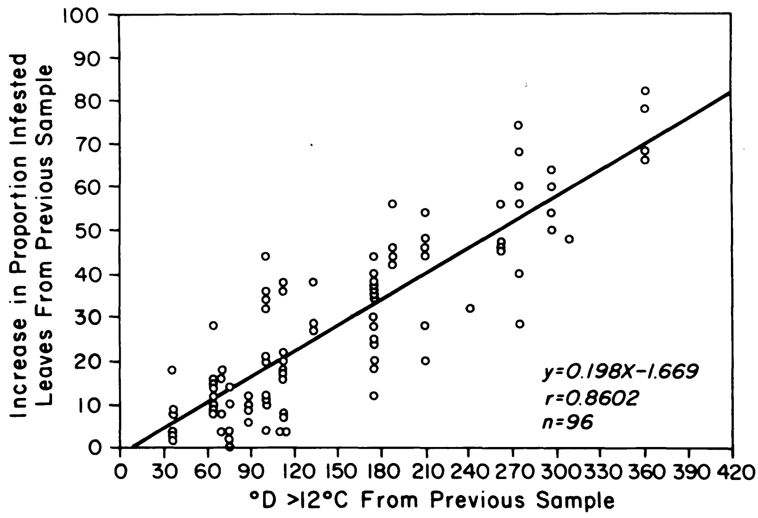

Fig. II.4. Relationship between increase in proportion leaves infested with *Tetranychus* spp. mites between sampling dates, and accumulated heat (°D>12° C) for the same period.

distribution of *T. urticae* in almond orchards. Early in the season, mites are concentrated on lower portions and tree centers, then disperse to the outside of the tree to become uniformly distributed. High densities of mites before this dispersal rarely occur unless the system has been disturbed by pesticides. Wilson et al. in the first paper have shown that after mid-June, leaves removed randomly from any portion of the tree above the sprinkler line will provide an accurate estimate of web-spinning mite abundance. Westigard and Calvin (1971) found similar patterns of *T. urticae* distribution on pear in Oregon.

Implementing presence-absence sequential sampling for web-spinning mites requires the ability to identify both the predator mite *M. occidentalis* and the *Tetranychus* spp. complex, familiarity with the orchard to help identify areas of potential outbreaks, and sampling decision rules.

The grower or pest manager should initiate the monitoring program in mid-June, randomly sampling leaves for predators. Hoy and Smilanick (1981) suggest that predatory mites are most often associated with colonies of spider mites due to the presence of kairomones. Predators other than *M. occidentalis*—such as *Stethorus* spp., *Chrysopa* spp., and *Scolothrips sexmaculatus* (Pergande)—can be seen (McMurtry et al. 1970). Their presence should be considered before taking a pest management action as they may cause tetranychid mite populations to decline. The presence or absence of *M. occidentalis* will determine which sampling decision rules to use.

To develop sampling forms, the grower or pest manager must decide the number of leaves that can be economically sampled and the minimum portion of the orchard on which a treatment could be applied. If the orchard can be divided into more than one unit with respect to spider mite levels, each portion of the orchard should be sampled independently. Certain portions of the orchard have greater potential for mite outbreaks such as areas adjacent to roadways or with sandy soil. These areas should be sampled separately if it is possible to treat only those portions of the orchard. Trees within each unit should be sampled at random; however, the trees chosen should not be obviously different from others in the unit.

Once an appropriate sampling plan has been devised (such as that illustrated by table II.2) sampling can begin. The grower or pest manager picks the suggested number of leaves from the first tree. The leaves should be selected at random around the circumference of the tree above the spinkler line. Each leaf should be examined for the presence or absence of any life stage of *Tetranychus* mites. There is no need to count the number of mites per leaf. The number of leaves containing one or more web-spinning mites should be recorded in the proper column. As more trees are sampled, the sum of leaves with web-spinning mites for all trees should be accumulated in a second column. If the accumulated number of leaves containing one or more web-spinning mites is equal to or exceeds the number in the column labeled "treat if greater than or equal to," a treatment is justified. If the accumulated number of leaves with mites is less than or equal to the column labeled "don't treat if less than or equal to," no treatment is necessary. When either a "treat" or "no treat" decision is reached, sampling can be terminated. If no decision can be reached, continue sampling as long as time constraints permit. At least five trees should be sampled from each orchard unit.

The presence-absence sequential sampling plan provides an estimate of whether or not a treatment is required and may be used as part of a weekly orchard monitoring program. It does not provide an estimate of population growth rates or whether a treatment level will be reached at some time in the future. If greater than once a week, sampling frequency should be based on the potential development of mite populations. This can be assessed by using the relationship of increasing proportion infested leaves for a given number of degree-days greater than 12° C. By calculating the difference in proportion infested leaves in the current sample with the proportion infested leaves for the provisional control decision threshold and relating this to the potential increase in proportion infested leaves for a given number of degree-days greater than 12° C, it is possible to determine the number of degree-days that would be required in the subsequent week to reach the control decision threshold. The presence-absence monitoring plan could prove especially valuable when used after mid-June in orchards where mites have the potential to become a problem due to cultural practices, insufficient predator abundance, or pesticide intervention. It can also be used in orchards where the predator *M. occidentalis* is found, and should follow an early season program of monitoring *Tetranychus* mite and predator densities and applying low dosages of acaricides when necessary to reduce high early-season infestations.

Literature Cited

AVERY, D. J., and J. B. BIGGS

1968 Damage to leaves caused by fruit tree red spider mite, *Panonychus ulmi* (Koch). J. Hort. Sci. 43:463-73.

BARNES, M. M., and K. L. ANDREWS

1978. Effects of spider mites on almond tree growth and productivity. J. Econ. Entomol. 71:55-98.

BARNES, M. M., and R. K. CURTIS

1979. Present development of arthropod pest management in almond orchards in California. Pages 1-14 *in* D. J. Boethal and R. D. Eikenbary (eds.), Pest management programs for deciduous tree fruits and nuts. Plenum Press, New York.

BATEN, W., and R. HUTSON

1943. Precautions necessary in estimating populations of small animals. J. Econ. Entomol. 36:501-04.

BRITO, R. M.

1980. Factors affecting the distribution and abundance of 3 species of *Tetranychus* spider mites on cotton and the effect of their damage on transpiration and photosynthesis. Ph.D. Dissertation, Univ. Calif. Riverside. 124 pp.

BOUDREAUX, H. B.

1953. A simple method of collecting spider mites. J. Econ. Entomol. 46:1102-03.

CAGLE, L. R.

1949. Life history of the two-spotted spider mite. Tech. Bull. Virginia Agr. Exp. Sta. 113:31.

CHAPMAN, P. J., S. E. LIENK, and O. F. CURTIS

1952. Responses of apple trees to mite infestations. J. Econ. Entomol. 45:815-21.

CROFT, B. A., S. M. WELCH, and M. J. DOVER

1976. Dispersion statistics and sample size estimates for populations of the mite species *Panonychus ulmi* and *Amblyseius fallacis* on apple. Environ. Entomol. 5:227-33.

FOOTE, W. H.

1965. Geotactic response of the two-spotted spider mite, *Tetranychus urticae* Koch (Acarina : Tetranychidae) on greenhouse cucumbers. Proc. Entomol. Soc. Ont. 95:106-08.

HARRISON, R. A., and A. G. SMITH

1961. The influence of temperature and relative humidity on the development of eggs and on the effectiveness of ovicides against *Tetranychus telarious* L. (Acarina : Tetranychidae). New Zealand J. Sci. 4:540-49.

HENDERSON, C. F.

1960. A sampling technique for estimating populations of small arthropods in soil and vegetation. J. Econ. Entomol. 53:115-21.

HENDERSON, C. F., and H. V. McBURNIE

1943. Sampling technique for determining populations of the citrus red mite and its predators. Washington, D.C./USDA Cir. 671:1-11.

HOSKINS, W. M., A. M. BOYCE, and J. F. LAMIMAN

1938. The use of selenium in sprays for the control of mites on citrus and grapes. Hilgardia 12:115-75.

HOY, M. A., N. W. ROSS, and D. ROUGH

1978. Impact of navel orangeworm insecticides on mites in northern California almonds. Calif. Agric. 32(5):10-12.

HOY, M. A., and J. M. SMILANICK

1981. Non-random prey location by the phytoseiid predator *Metaseiulus occidentalis:* differential responses to several spider mite species. Entomol. Exp. et Appl. 29:241-53.

HUFFAKER, C. B., M. VAN DE VRIE, and J. A. McMURTRY

1970. Ecology of Tetranychid mites and their natural enemies: A review. I. Tetranychid populations and their possible control by predators: An evaluation. Hilgardia 40:391-458.

HUSSEY, N. W., W. J. PARR, and C. D. CROCKER
1957. Effect of temperature on the development of *Tetranychus telarius* L. Nature (London). 179: 739-40.
INGRAM, W. R., and S. M. GREEN
1972. Sequential sampling for bollworms on rain grown cotton in Botswana. Cotton Grow. Rev. 49: 265-75.
JEPPSON, L. R.
1951. New acaricides for control of citrus red mite, 1948-50. J. Econ. Entomol. 44:823-32.
JONES, L. S., and D. T. PRENDERGAST
1937. Method of obtaining an index to density of field populations of citrus red mite. J. Econ. Entomol. 30:934-40.
KARANDINOS, M. G.
1976. Optimum sample size and comments on some published formulae. Entomol. Soc. Amer. Bull. 22:417-21.
LEIGH, T. F., V. L. MAGGI, and L. T. WILSON
1984. A leaf wash arthropod extractor. J. Econ. Entomol. (in press).
McMURTRY, J. A., C. B. HUFFAKER, and M. VAN DE VRIE
1970. Ecology of tetranychid mites and their natural enemies: a review. I. Tetranychid enemies: their biological characters and the impact of spray practices. Hilgardia 40:331-90.
MICHELBACHER, A. E.
1959. Spider mites on walnut in Northern California. J. Econ. Entomol. 52:936-39.
MORI, H.
1961. Comparative studies of thermal reaction in four species of spider mites. (Acarina: Tetranychidae). J. Fac. Agric. Hokkaido (imp.) Univ. 51:574-91.
NEWELL, I. M.
1947. Quantitative methods in biological and control studies of orchard mites. J. Econ. Entomol. 40:683-89.
PIELOU, D. P.
1960. The effect of DDT on oviposition, and on behavior in the European red mite *Panonychus ulmi* (Koch). Can. J. Zool. 38:1147-51.
PIETERS, E. P., and W. L. STERLING
1975. Sequential sampling cotton squares damaged by boll weevils on *Heliothis* spp. in the Coastal Bend of Texas. J. Econ. Entomol. 68:543-45.
STERLING, W.
1975. Sequential sampling of cotton insect populations. Proc. Beltwide Cotton Prod. Conf. pp. 133-35.
SUMMERS, F. M.
1962. Insect and mite pests of almonds. Calif. Agric. Exp. Sta. Cir. 513:1-16.
SUMMERS, F. M., and G. A. BAKER
1952. A procedure for determining relative densities of brown almond mite populations on almond trees. Hilgardia 21:369-82.
VAN DE VRIE, M., J. A. McMURTRY, and C. B. HUFFAKER
1972. Ecology of tetranychid mites and their natural enemies: A review, III. Biology, ecology, and pest status, and host/plant relations of tetranychids. Hilgardia 41:343-432.
VENABLES, E. P., and A. A. DENNYS
1941. A new method of counting orchard mites. J. Econ. Entomol. 34:324.
WALD, A.
1945. Sequential analysis in inspection and experimentation. Columbia Univ. Press, New York.
WESTIGARD, P. H., and L. D. CALVIN
1971. Estimating mite populations in Southern Oregon pear orchards. Can. Entomol. 103:67-71.
WESTIGARD, P., P. B. LOMBARD, and J. H. GRIM
1966. Preliminary investigations of the effect of feeding of various levels of two-spotted spider mite on its Anjou pear host. Proc. Amer. Soc. Hort. Sci. 89:117-22.
WILSON, L. T., D. GONZALEZ, T. F. LEIGH, V. MAGGI, C. FORISTIERE, and P. GOODELL
1983a. Within-plant distribution of spider mites (Acari: Tetranychidae) on cotton: A developing implementable monitoring program. Environ. Entomol. 12:128-34.
WILSON, L. T., T. F. LEIGH, and V. MAGGI
1981. Presence-absence sampling of spider mite densities on cotton. Calif. Agric. 35:10.
WILSON, L. T., C. PICKEL, R. C. MOUNT, and F. G. ZALOM
1983b. Presence-absence sequential sampling for cabbage aphid *Brevicornye brassicae* (L.) and green peach aphid *Myzus persicae* (Sulz.) on Brussels sprouts. J. Econ. Entomol. 76:476-79.
WILSON, L. T., and P. M. ROOM
1983. Clumping patterns of fruit and arthropods in cotton with implications for binomial sampling. Environ. Entomol. 12:50-54.
ZALOM, F. G., and L. T. WILSON
1982. Degree-days in relation to an integrated pest management program. Univ. Calif. Div. of Agric. Sci. Leaflet 21301. 2 pp.